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Hydrology and
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Interactive comment on "*HESS Opinions* "Ensembles, uncertainty and flood prediction"" *by* S. L. Dance and Q. P. Zou

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Response to Pappenberger et al.

We would like to thank all the authors of this comment for their careful consideration of our paper. Their comments have added depth to the discussion, from the hydrological perspective. We were very pleased that our paper provoked such a substantial and rapid response!

We note that the our paper was intended as a cross-cutting discussion of common issues arising in ensemble methods for all types of flood risk prediction, i.e., using meteorological, hydrological and oceanographic models, over a range of time and space

scales. So while we agree that in the individual sub-disciplines some of the problems may have already been partially answered or are being currently explored, not all areas of research are at the same level of maturity. For example, while there are already operational systems for ensemble predictions of fluvial floods in large European catchments (Thielen et al., 2009), the use of ensemble methods in conjunction with a chain of meteorology, ocean and coastal models for evaluating the risk of overtopping of flood defences in coastal floods has only recently been attempted (Zou et al., 2008). We would also argue that even in areas where the use of ensemble methods is mature, new developments often mean revisiting the same questions, and proposing new solutions. For example, the sorts of ensemble perturbations useful for medium range numerical weather prediction are not necessarily optimal for convective scale numerical weather prediction (e.g., Leoncini et al., in press).

We agree that the paper would benefit from a greater discussion of context, and we will incorporate some of your suggested references and projects in our revised manuscript. However, please bear it in mind that this paper is not meant to be a review paper of publications in ensemble methods applied to meteorology, oceanography/coastal engineering and hydrology.

Uncertainty in initial conditions, boundary conditions and forcing data; Parameter errors and Model structural errors

We agree that there is more than one approach to uncertainty analysis and we think your comments have highlighted interesting philosophical differences between these approaches. However we have tried to limit the scope of the paper to ensemble methods where the Bayesian approach is natural. We will incorporate the additional references you suggest in our revised manuscript, where they are relevant to ensemble methods. One of the reasons that ensemble methods have been widely adopted is that their computational cost is small enough to be feasible with large complex systems. While ensemble techniques typically do undersample the state-space they are still able to provide useful information by preferentially choosing dynamically unstable directions for ensemble perturbations. This is not the case for some of the other purely statistical techniques that you discuss such as MCMC (Vrugt et al., 2003, 2008) and particle filters (Salamon and Feyen, 2009), which suffer from the "curse of dimensionality," and are not feasible for large systems.

We omitted to discuss post–processing of ensemble predictions, since this was not discussed in detail at the workshop, and thus we considered it beyond the scope of our paper. Nevertheless, it is clear that raw ensemble validation and verification is a required first step before model output statistics can be computed and this is discussed in section 7 of our paper.

Ensemble validation or verification

Regarding our comment that the "knowledge of properties of existing skill scores used routinely in NWP is not yet widespread in the flood prediction community," this remark was based on reactions at the workshop, where we had the impression that a substantial number of attendees wished to know more about NWP skill scores.

Propagation of uncertainty between models

Pappenberger et al. point out that the land-surface schemes used in NWP and models used in hydrology are intrinsically decoupled. A current focus in NWP is to improve the representation of hydrological (and other) processes in land-surface models (e.g., ECMWF/GLASS workshop 2009). Some land-surface schemes such as JULES: The Joint UK Land Environment Simulator (Blyth et al., 2006) can be run stand-alone, or as a land-surface scheme for a meteorological model (such as the UK Met Office Unified Model). This enables them to be tested separately, i.e., uncoupled from the meteorological model and its inherent biases, as well as in the context of forecasting or climate prediction. The availability of new observation types such as soil moisture observations from the newly operational SMOS satellite, and the development of improved land data assimilation schemes will also push advances by confronting the models with observations.

NWP has also been improved by better parameterisations of air-sea interactions. As pointed out by our paper, Peter Janssen and others at ECMWF demonstrated the benefits of using a two-way coupled wave-atmosphere model for global modeling of wind and waves. (Janssen (2004))

Additional References

Blyth, E., et al., 2006, JULES: a new community land surface model. Glob. Change News., No. 66, October 2006.

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